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INVESTIGATIONS ON LIGHT AND HEAT, MADE AND PUBLISHED WHOLLY OR IN PART WITH
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XI.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XLV.—MELTING POINTS OF ALUMINUM, SILVER, GOLD, COPPER, AND PLATINUM.

BY S. W. HOLMAN, WITH R. R. LAWRENCE AND L. BARR.

Presented November 13, 1895.

THE following melting points are offered as provisional only, but with the belief that they are more reliable than previous data. The absolute values depend in part upon the assumption of 1072° C. as the melting point of pure gold, the recent determination of Holborn and Wien at the Reichsanstalt. Should that datum, however, be shown to require revision, the validity of the present measurements would not be impaired, but new values of the melting points could be readily computed from them, which would be consistent with the better value for gold.

Al	Ag	Au	Cu	Pt
660°	970°	$[1072^{\circ} \text{ C.}]$	1095°	1760°
		Assumed.		

The Pure Metals used were of a high degree of fineness, except unfortunately the platinum.

The gold contained less than 0.01 per cent total impurities, these being, if any, probably minute traces of silver and platinum. It was obtained as part of a specially prepared lot from the United States Assay Office in New York through the courtesy of Professor H. G. Torrey, upon whose authority the above statement is made. The purity was at least as great as the best "proof" metal used at the United States or London mints.

The silver was from the same source, and equally pure.

The aluminum was manufactured and given by the Pittsburg Reduction Company, of Pittsburg, Penn., and was stated by Mr. Alfred E.

Hunt, President of the company, to contain but 0.07 per cent of impurity, consisting entirely of silicon.

The platinum was the ordinary platinum wire supplied by Carpentier of Paris with his Le Chatelier thermo-electric pyrometers. It presumably contained 0.5 per cent or more of impurity.

The copper was electrolytically produced, and was from the Lake Superior region. It was kindly given by Mr. Maurice B. Patch of the Buffalo Smelting Company, Buffalo, N. Y., who stated that it showed by analysis 99.99+ per cent of Cu, and contained no Ag, As, or S, and only 0.0002 per cent of Fe.

The Less Pure Metals. — Partly for the purpose of testing the effect of impurities, other samples of gold and copper were employed with the results stated later. These were: —

Dentists' Gold. — This was a gold foil employed by dentists, purchased as being of good quality.

Ingot Copper. — This was also from Mr. Patch of the Buffalo Smelting Company, who gave its analysis as

Cu	99.825
Ag	0.032
As	0.003
S	0.022
Fe	0.003
O	0.116
	<hr/> 100.001

This was the company's "regular run" of copper.

Commercial Electrolytic Copper. — A sample of commercial electrolytic rolled sheet copper, furnished by a friend, and not assumed to be of unusual purity. It was probably Montana copper.

Commercial Hard-drawn Copper Wire. — This was from a lot purchased for electrical testing purposes, which showed a specific resistance of 0.1440 international ohms per meter-gram, or an electrical conductivity of about 98.3 per cent referred to Matthiessen's copper.

Methods and Apparatus. — The method consists in measuring the thermal electro-motive force of a couple composed of one wire of platinum and the other of a 10 per cent rhodo-platinum alloy. One junction is immersed in the melting or solidifying metal, and the other surrounded by ice. The wire was that furnished by Carpentier of

Paris (through Queen & Co. of Philadelphia) with the Le'Chatelier pyrometer.

The emf. was measured in microvolts (international) by the Poggendorff null method modified for rapid and convenient working. The disposition of apparatus is shown in Figure 1. *B* is a battery of sufficiently steady emf. (A single Samson-Leclanché cell was entirely satisfactory.) In direct circuit with this were two water rheostats, *W*, in series; an ammeter, *A*, which was a Weston voltmeter (No. 395) with the calibrating coil only in use; and a manganine

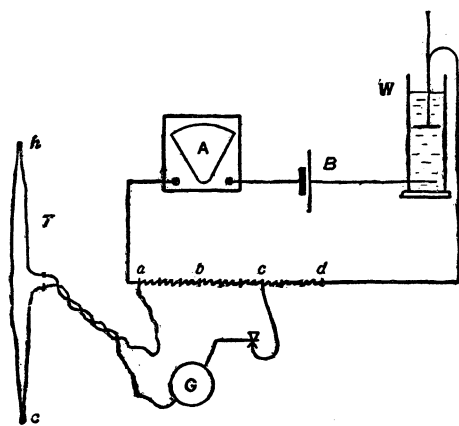


FIG. 1.

wire resistance, *a*, *b*, *c*, *d*, divided into sections, each of accurately known resistance. *T* is the thermo-couple connected through a sensitive galvanometer, *G*, and key to any desired sections of the coil *a*, *b*, *c*, *d*. The water rheostats were of about 100 ohms and 8 ohms respectively, and the vertical motion of their plungers thus served to give a coarse and fine adjustment to the resistance in the circuit.

The current could thus be promptly and closely adjusted. The voltmeter was one of the type having a "calibrating coil," that is, one having a connection by means of which the usual high resistance series coil could be cut out, leaving its resistance about 117 ohms. Any of the Weston voltmeters with a special connection made to effect that result would answer equally well. The voltmeter was preferred to a mil-ammeter as probably more reliable. The instrument was carefully and repeatedly calibrated throughout its scale by an application of the Poggendorff method, measuring by the Clark cell the drop of potential in a known resistance through which a current was passing in series with the ammeter, and at the same instant reading the ammeter. The calibrations at different times checked at the same point, with an average deviation of only a few hundredths of one percent. A test for temperature error showed a change of but 0.1 percent for a change of 15° C.; so that, as the temperature during the work was constant

within a few degrees, no correction was needed. The manganine coil Figure 2, consisted of about 16 feet of No. 20 wire, had a total resistance of about 8.8 ohms, and was divided into nine sections by copper potential wires leading into different points along the coil. These sections were so designed that by suitably shifting the connections along *a, b, c*, etc., any thermal emf. which was to be measured could be balanced by a current which would deflect the ammeter to a point between 90 and 140 divisions (readable to tenths), — corresponding to currents from 0.006 to 0.009 amperes roughly. The coil was immersed directly in kerosene, and, as its temperature coefficient was but 0.001 per 1°C ., the correction became very small. The relation and actual resistance (international ohms) of the whole coil and its several sections were repeatedly determined against a standard ohm by the differential galvanometer, and checked by a modified Wheatstone bridge arrangement. These data were reliable probably well within 0.05 per cent throughout.

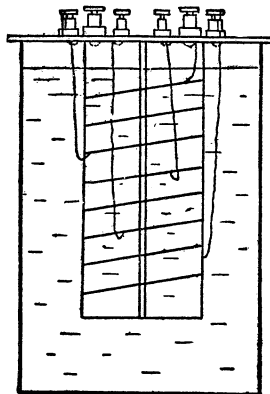


FIG. 2.

In the thermo-couple circuit, the sensitiveness necessary in the galvanometer to give the smallest emf. to 0.1 per cent was easily computed to be only about $7.7 \cdot 10^6$ (mm. defl. at 1 m. per ampere or *d/c*). The instrument as actually used exceeded this requirement, averaging about $5 \cdot 10^7$. Its resistance, all in series, was 14.3 ohms.

The cold junction *c* of the thermo-couple was fused together in an oxyhydrogen flame. The wires, insulated from each other by having one strung through a very fine glass tube, were run down another tube of about $\frac{1}{8}$ inch inside diameter, and 8 or 10 inches long. This tube was fused together at the bottom and top, as well as at some intermediate points, and when in use was always packed in a double vessel of cracked ice, as shown in Figure 3.

The intermediate junctions from which the copper leads went off to galvanometer and key were soldered. They were kept at an equal temperature by the device of enclosing them in a stoppered glass tube, which was packed with hair felt into a one-inch hole in a five-inch cube of cast iron. This arrangement was entirely satisfactory, but seems to possess no material advantage over making the junction of the copper leads with the Pt and Pt Rh serve as the cold junction, and

immersing this in ice as in Figure 3, except that the latter makes a rather more bulky mass to insert in the ice.

The wires were also fused together at the hot junction except when this was unnecessary on account of their being immersed in metal. It may be noted here that, as a null method was employed, the total resistance of the thermal circuit, or any variation in it, was without effect other than a corresponding change in sensitiveness.

As the hot junction was to be immersed in vapor of sulphur as one of the known temperatures, the following apparatus was designed for this purpose. It is substantially the sulphur boiling point apparatus

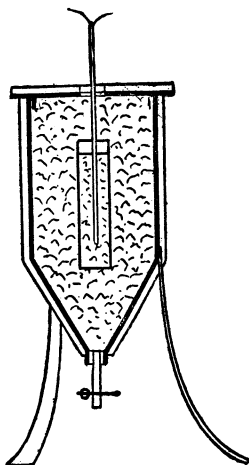


FIG. 3.

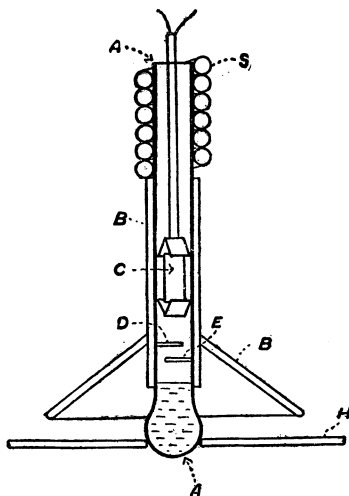


FIG. 4.

of Griffiths, and is shown in Figure 4. A glass tube, *A*, similar to the Victor Meyer vapor density tube, 16 inches long and with a two-inch bulb, was provided with an asbestos jacket and hood, *B*, *B*. The upper few inches of the tube were wound with a spiral wire spring, *S*, which rendered this part efficient as a condenser. The top was closed with a layer of asbestos. Two overlapping diaphragms of asbestos were inserted in the tube at *D* and *E*. The couple passed downward through a glass tube to the asbestos tubular hood, *C*, which served as an umbrella to shed the dripping cooler sulphur, and as a radiation screen. The hood, however, had openings top and bottom for the free circulation of the vapor. An asbestos diaphragm, *H*, upon which the bulb rested, reduced the chances of superheating.

For the melting metals, after trial of several devices, the one shown in Figure 5 (of exactly half size) was settled upon as proving very satisfactory. The crucible *C* (usually of fire clay) is supported by clay blocks in the double-walled fire-clay furnace, *F*. A carbon block, *E*, channelled to fit the crucible, forms its cover, and a carbon diaphragm *D* inside the crucible serves to support some powdered carbon shown by the dotted mass. The object of these carbon parts was to prevent oxidation of molten metals, and they proved very effective in the case of aluminum, silver, and copper. *G G* was an

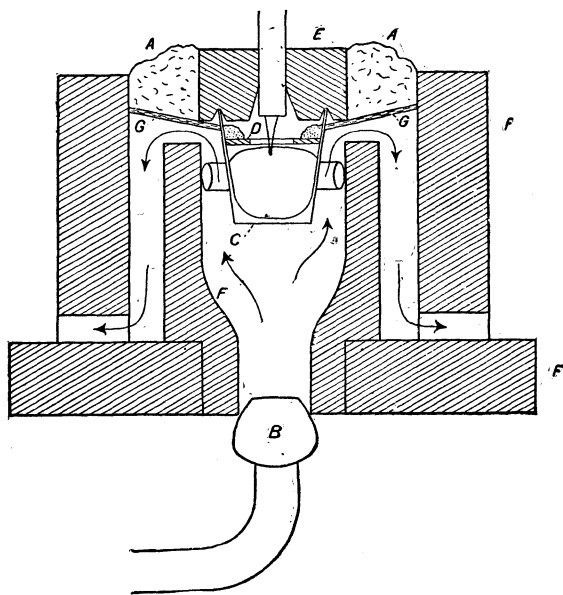


FIG. 5.

asbestos diaphragm supporting a non-conducting layer of fibrous asbestos, *A, A*. The temperature was controlled by the blast lamp *B*. The clay crucible was one inch in diameter outside, and the amount of metal employed ranged from 11 grams (gold) to 35 grams (copper). Larger amounts might be advantageous, but with 30 to 35 grams it was easily possible to obtain a constant indication for five minutes during the melting or solidifying of copper. No difficulty whatever was experienced with this arrangement with silver, gold, or copper. With aluminum, however, a peculiar action occurred, the cause of which in the time available for investigation could not be determined

beyond doubt. The phenomenon was that after a few minutes of constant temperature at the melting point the indication of the thermocouple fell off with increasing rapidity. On withdrawing the couple, cleaning it, or clipping it off and restoring it to place, the melting metal meanwhile being untouched, the indications returned to their original high value. The apparent explanation was the formation of a slag between the wires, but this was not entirely satisfactory. The use of a plumbago crucible in place of the clay, and an entirely fresh lot of aluminum, did not remove the phenomenon, and gave the same initial readings, which it could not be doubted were the ones corresponding to the melting point. The fusion of the aluminum was, however, the least sharply defined of all the metals used.

The fusion of platinum was, of course, differently effected. For this the two wires of the couple were laid close together on a piece of lime. An oxy-hydrogen flame was then directed upon their ends, and the platinum fused into a globule which with care could be made to travel slowly up the wire. There was no difficulty in obtaining steady temperatures for a sufficient period to make the necessary readings, and check results to 0.1 per cent were obtained on different days.

The galvanometer, keys, coils, and all junctions of dissimilar metals, were, so far as possible, covered with boxes of wood, pasteboard, or asbestos, to maintain uniformity of temperature, and thus minimize local thermo-electric disturbances. With this precaution no sensible trouble from that source was experienced.

The procedure is as follows. To take the observation for vapor of sulphur, for instance, the hot and cold junctions are exposed as described. After a sufficient time the main circuit is closed, the thermal circuit is connected to a suitable part of a , b , c , d , and the rheostats, W , are adjusted until on pressing the key no deflection occurs in the galvanometer, G . At this instant, A is read, which gives the current c in the main circuit. The adjustment is disturbed and remade a number of times, and the resulting readings should check to the nearest tenth of a division of A , provided the metal has reached a steady state of temperature.

By this adjustment the drop of potential $c r$ due to the current c amperes in the part r ohms of the resistance a , b , c , d , spanned by the thermal circuit, is made equal to the total resultant emf. in the thermal circuit. The latter, which will be denoted by $\Sigma_c^h e$ or $\Sigma_c' e$, is the algebraic sum of the thermal emf. proper of the junctions of the Thomson emf. in the wires, and of any "stray" or local thermal emf.

in the circuit. The last was found to be negligible throughout the work.

To observe the melting point, the furnace containing the metal is heated more or less rapidly until the melting point is approached. The blast lamp is then adjusted to give a slowly rising temperature. The thermal circuit, with the couple previously fused into the metal, is connected to a suitable section of a, b, c, d . The rheostats are continually adjusted for zero deflections of the galvanometer, G , and the corresponding readings of A are taken. These will show gradually increasing values, but the rise will presently be interrupted by a series of constant readings, after which the readings will again steadily increase. This period of constant, or nearly constant, readings of A is that in which the latent heat of fusion is being absorbed, and its duration is frequently several minutes. The temperature at that time is, of course, that of the melting point. The reverse process, starting with the metal in a molten state and cooling it gradually, shows a similar period of solidification.

No difference was discovered between the ascending and descending readings when a sufficient amount of the metal and a slow rate of heating and cooling were employed. With small amounts the steady reading was more or less masked by phenomena which were clearly due to inequality in distribution of temperature throughout the mass of mixed liquid and solid metal. In the case of aluminum, however, something more than this irregularity was observed, as elsewhere stated, but the time at command did not permit a study beyond the point of satisfying ourselves that the point observed was unquestionably the true melting point.

This work was done chiefly as the thesis work of Messrs. Lawrence and Barr. The efficient assistance of Mr. C. L. Norton contributed materially to its progress and success.

The computation of temperatures t from the observed electro-motive forces Σe involves a knowledge of the function connecting the two, i. e. of the function

$$\Sigma_0^t e = f(t) \quad \text{or} \quad t = F(\Sigma_0^t e).$$

This problem has been elsewhere discussed by one of the authors of this paper.*

In that article two interpolation formulæ were developed. They were respectively of the following forms, applying to the case where

* Holman, These Proceedings, *ante*, p. 193.

one junction of the couple is kept at 0° C., and the other is at any other temperature t C., or $\tau = t + 273^{\circ}$ absolute; m and n are constants, different for the two expressions; $\Sigma_0^t e$ denotes the resultant thermal emf. of the circuit, viz. that which is the object of direct measurement. The first, called the exponential equation, is

$$\Sigma_0^t e = m \tau^n - \beta \quad (\text{where } \beta = m \tau_0^n = m \times 273^n).$$

The second expression, called the logarithmic equation, is

$$\Sigma_0^t e = m t^n, \quad \text{or} \quad \log \Sigma_0^t e = n \log t + \log m.$$

Both formulæ have been applied to the data of the present investigation given in Table I., with results shown below. The Avenarius formula has also been applied for purposes of comparison.

To evaluate the constants m and n of the exponential equation (for method, consult the paper referred to) it is necessary to have values of $\Sigma_0^t e$ at three known temperatures. Of these, however, one may be $\Sigma_0^t e = 0$, at $\tau = 273^{\circ}$, i. e. with both junctions in ice. It therefore remains to fix upon two other temperatures between which to interpolate, or, in other words, two other temperatures which shall be assumed as known. In looking over the ground it seemed that the boiling point of sulphur, being so high and so accurately determined by Callendar and Griffiths,*

$$444.53 + 0.082 (H - 760),$$

was pre-eminently one of these points. The other must be much higher, and the melting point of pure gold seemed to be almost, if not quite, the only one upon which reliance could be placed.

Apart from freedom from oxidation, and its conveniently high point of fusion, gold seemed the more suitable because its melting point had recently been so carefully measured by Holborn and Wien, and because the metal could be obtained of the necessary purity. Add to these considerations the fact that its melting point in a state of at least fairly high purity has been measured by more experimenters than that of any other high melting metal, so that it serves as an excellent connecting link between their work, and we have claims which no other substances can at present offer. The fusion point of gold was therefore chosen as the second reference or calibration temperature. As to the figure to be assumed as the melting point of gold there is room for differences of opinion. The claims of the work

* Phil. Trans. CLXXXII, 119, 157 (1891).

of Holborn and Wien, supported to some extent by considerations advanced by Barus,* lend much weight to the conclusion that Violle's value of 1035° is considerably too low. Granting this, and in the absence of sufficient basis for the assignment of weights to the work of divers other investigators, the simplest and best step seemed to be to adopt provisionally, without modification, Holborn and Wien's value,

$$1072^{\circ}.$$

These two points settled upon, the constants m and n could be computed as elsewhere described, and the equation transposed to deduce other values of t from observed values of $\Sigma_0^t e$. Representing $m \tau_0^n$ by β , a constant, the equation for the temperature as a function of $\Sigma_0^t e$ takes the form

$$t = \sqrt[n]{\frac{\Sigma_0^t e + \beta}{m}} - 273^{\circ},$$

which is, of course, easily solved by logarithms.

The data given in Table I. yield the values $m = 0.3901$, $n = 1.488$, $\beta = 1645$, in international microvolts and degrees centigrade, so that

$$\Sigma_0^t e = 0.3901 \tau^{1.488} - 1645, \quad \text{or} \quad t = 1.488 \sqrt[n]{\frac{\Sigma_0^t e + 1645}{0.3901}} - 273.$$

From these the temperatures of column six have been computed.

The constants of the logarithmic formula have been computed from the same data for sulphur and gold, the method being sufficiently obvious. The equation becomes

$$\Sigma_0^t e = 2.49655 t^{1.2563}.$$

The corresponding melting and boiling points are given in Table I., column seven.

Substitution of the same data in the Avenarius equation yields

$$\Sigma_0^t e = (t_h - t_c) \{9.7335 + 0.0048449 (t_h + t_c)\}.$$

The corresponding melting and boiling points are given in column five.

PROVISIONAL VALUES OF MELTING POINTS.

In the paper referred to it was shown, 1st, that the logarithmic expression fitted the Barus comparisons of the irido-platinum couple with the air thermometer within the limits 400° to 1200° C. with no

* Am. Jour. Sci., XLVIII. 336.

sensible systematic error ; 2d, that the exponential equation similarly fitted the Holborn and Wien comparison of the rhodo-platinum couple with the air thermometer within the same limits ; 3d, that the exponential equation diverged systematically, although slightly, from the Barus data, and the logarithmic from the Holborn and Wien data, by about equal and opposite amounts both inside and outside these limits, but much more markedly between 0° and 400° than at higher points.

TABLE I.
MELTING POINTS.

Date.	Subst.	Σe Micro- volts.	Temperatures.					Provis- ional Values.
			Assumed as Cor- rect.	From Aven. Eq. t_a .	From Exponent Eq. t_e .	From Log Eq. t_l .	$\frac{t_e + t_l}{2}$	
3-?	H ₂ O	885.8	99.64					
4-10	H ₂ O	890.4	100.57					
		888.1	[100.10]	87.4	91.7	107.3	99.5	
3-15	C ₁₀ H ₈	2213	218.3					
3-23	C ₁₀ H ₈	2224	218.9					
3-25	C ₁₀ H ₈	2216	218.2					
		2218	[218.5]	206.6	211.4	222.4	216.9	
3-?	S	5287	444.7					
3-22	S	5289	445.2					
3-29	S	5287	444.5					
		5288	[444.8]					
4-24	Cu	16463	—	1095.	1095.0	1096.5	1095.5	1095
4-29	Au	16002	[1072]	—	—	—	—	[1072]
4-29	Ag	14093	—	975.	972.	969.	970.5	970
5-2/3	Pt	30313	—	1695.	1735.	1783.	1759.	1760
5-3	Al	8638	—	665.5	662.5	656.2	659.4	660

Aven. $\Sigma_0^t e = (t_2 - t_1) \{9.7335 + 0.00\ 484\ 49\ (t_2 + t_1)\}.$

Exp. $\Sigma_0^t e = 0.3901\ \tau^{1.488} - 1645.$

Log. $\Sigma_0^t e = 2.49655\ t^{1.2563}.$

Inspection of columns six and seven, Table I., will show that the computed boiling points of water and naphthalin by the exponential and logarithmic equations depart widely from the known temperatures in opposite directions, by about equal amounts, and in the directions according with the departures from the Barus and Holborn and Wien data. Also, that the differences between the computed melting points intermediate between sulphur and gold differ but slightly by the two formulæ, thus confirming the former conclusions. It is obvious, therefore, that although either of the two formulæ would yield fairly good interpolations for Al, Ag, and Cu, yet that a mean between the two would probably quite nearly offset against each other the systematic errors of the respective equations. This is also true in the dangerous process of extrapolation for the platinum melting point, where the chances of error in the result seem to be probably very much reduced by averaging. The means of the melting points computed by the exponential and logarithmic equations are, therefore, regarded as the nearest available approximations, and the round numbers of column nine are adopted as provisional values to represent the results of the work.

Comparison of the results of the Avenarius formula, column five, will show that they depart widely from the others in the direction which would have been anticipated from the conclusions of the previous paper, thus further strengthening those inferences.

In addition to the foregoing, the melting points of three other samples of copper, and one other of gold, were measured. The gold was dentists' gold "foil," purchased in Boston. This is usually classed as "very nearly pure," but its analysis was not known. No special interest, therefore, attaches to it beyond the indication that it gives of the sign and order of magnitude of the error (about -4°) which would be introduced by the use of such gold in the calibration of the Le Chatelier pyrometer, or in similar ways.* The melting point was found to be 1068° .

The four coppers yielded the appended results.

* Holman, Calibration of the Le Chatelier Thermo-electric Pyrometer. See These Proceedings, *post*, p. 234.

TABLE II.

Σe Microvolts.	Melting Points, C.	Purity of Metal.	Description.
16463	1095.0	99.99+	Electrolytic. Probably Lake Superior copper, Buffalo Smelting Co.
16448	1094.3	99.83	Ordinary ingot. Same source.
16456	1094.7	Unknown.	Electrolytic. Probably from Montana.
16446	1094.2	Unknown.	Commercial hard drawn wire from Washburn and Moen Co. Sp. Elect. Conductivity (referred to Matthiessen value) 98.3 per cent.

The concordance of these results on various coppers, together with the completely satisfactory behavior of the metal in fusion, and the ease and cheapness of obtaining the metal of a very high grade of fineness, suggest the decided availability of copper in a direct study of high temperatures or melting points by the gas thermometer. A large mass of the metal could be employed, and a constant and uniform temperature for a protracted period thus secured for the bulb of the gas thermometer, or for other apparatus immersed in the molten or solidifying material. There are unfortunately too few substances which fulfil even these requirements. An added merit lies in the nearness to the gold melting point, enabling the two to be satisfactorily connected by some means of relative measurement.

It also appears that the use of good commercial copper would introduce sensibly less error (3° less) into the calibration of the Le Chatelier pyrometer than the use of the "dentists' gold" above tested, which is as good metal as would readily be obtained in the market by most observers.

Reliability of the Results. — The points involved are: —

Instrumental errors.

Purity of the metal.

Was the observed point the real melting point?

Validity of the interpolation equation.

Error in the assumed melting point of gold and boiling point of sulphur.

The investigation was planned and the apparatus arranged with the intention of reducing the combined instrumental errors below one

tenth of one per cent in the measurement of Σe above 200°C. Tests, check measurements, and a discussion of the sources of error, unnecessary to detail here, have given satisfactory demonstration that an even higher accuracy than this was attained. As far, therefore, as constant or variable instrumental errors are concerned, it is believed that no error beyond 0°.5 to 1° C. exists in the results, while probably this estimate is large.

The error from impurities must have been exceptionally small, as the analysis of the metals indicates. Some impurities from alloying with the platinum and rhodium of the thermo-couple must have entered during the experimenting, but as results at different stages of the work checked those obtained upon the first use of the metal, and as renewals of the metal made no difference in readings beyond the limits of other variations (about 5 parts in 10,000), the error from this source must have been negligible.

In the case of platinum the metal at command was unfortunately not of known composition, nor was it possible at the time to obtain any whose purity was known. An analysis of the wire used may perhaps be obtained later, and it is hoped to carry out further measurements with the better platinum now obtainable through the recent advances made in its manufacture in Germany and England.

The aluminum was of very high grade, but it is thought that still better may be obtained, and the peculiar occurrence attending its melting point measurements should be further investigated.

The actual effect of the small impurities cannot be numerically estimated, but must have been inconsiderable except for platinum, where the error probably has the positive sign.

As to the third point, there was no reasonable doubt left in the minds of the observers that the observed temperatures were sensibly the melting points. Except as noted for aluminum, the readings with rising and falling temperatures did not exceed about one part in one thousand. Also entirely independent observations on separate days, and with renewals of the metals in some cases, were equally concordant. The average difference was much less than the error of reading the ammeter. As an example of the concordance, and at the same time as showing the homogeneity of the thermo wire, three calibrations in sulphur are quoted in Table III.

TABLE III.

Date.	Σe Microvolts.	Computed Temperature of Sulphur.	Σe reduced to 445°.
March ?	5287	444.73 ^o	5290
March 22	5289	445.18	5287
March 29	5287	444.53	5293

Between these observations a considerable length of the wires was necessarily clipped off. Reduced to a common temperature of 445°, the maximum difference is but 6 microvolts in 5290, or 0.11 per cent, while the average deviation of a single observation is but 0.02 microvolts, or 0.04 per cent, and of the mean but $0.02/\sqrt{3} = 0.012$ microvolts, or 0.024 per cent. At higher temperatures the discrepancy was even smaller.

The validity of the interpolation formulæ has been already discussed. A statement of the extreme error which may have been introduced into the results by this source should however be added. This is believed to be for aluminum less than $\pm 2^\circ$, for silver less than $\pm 2^\circ$, for copper less than $\pm 0.5^\circ$, and for platinum less than $\pm 10^\circ$.

Comparison with the temperatures computed by the Avenarius equation show errors by the latter to be about 1.5 times as great for water and naphthalin, and of the same signs. It is therefore much less reliable, especially for the platinum temperature, and no weight is attached to its results.

Melting Points by various Authorities.—A collection of these is given in Table IV. Except in the case of the Barus data, the results are set down directly as given by their authors. A further discussion of these with reference to the purity of the metals used, and the characteristic errors of the methods employed, would doubtless prove instructive, and might partly remove or account for some of the apparent discrepancies, — a task which will perhaps be undertaken later.

TABLE IV.

Authority.	Date.	Method.	Metals.				
			Al	Ag	Au	Cu	Pt
H, L., and B. . . .	1895	Th.-el.	660	970	[1072]	1095	1760
Violle	1879	Sp. Ht.		954	1035	1054	1775
Ledebur	1884	Sp. Ht.		960		1100	
Le Chatelier		Th.-el.	635		[1035]		
Callendar				[945]	1037		
Erhard and Schertel .				954	1075		
Barus, by Log. Eq.* .	1894	Th.-el.	641	985	1090	1095	1783
“ by Eq. 3	“			986	1091	1096	1757
Holborn and Wien . .	1892	Th.-el.		968	1072	1082	
Mean of independent absol. meas'ts, i. e. exclud. H., L. & B., Le C., and C.			641	964	1068	1083	1779

N. B. — Values in brackets [] are those assumed by the observers, and upon which their other values depend to a greater or less extent.

* See discussion by Holman, *ante*, p. 193.

ROGERS LABORATORY OF PHYSICS,
MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
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